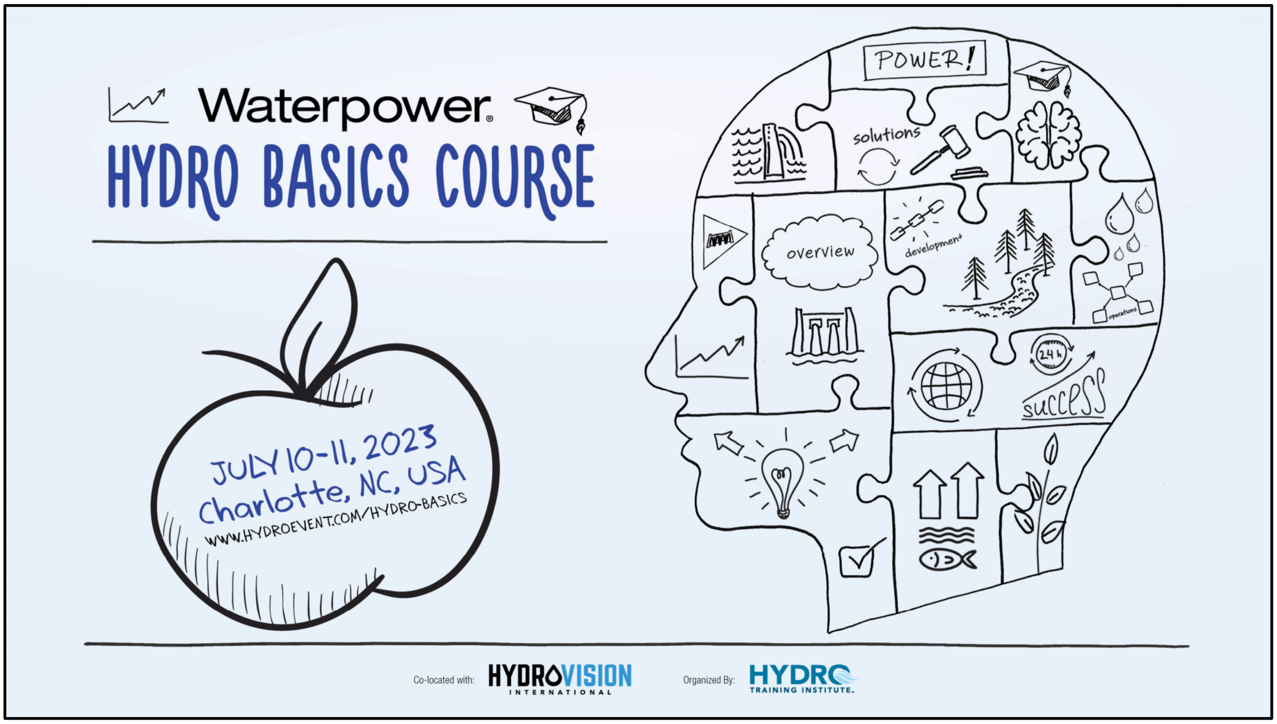

Waterpower®
HYDRO BASICS COURSE
JULY 10-11, 2023
Charlotte, NC, USA
WWW.HYDROEVENT.COM/HYDRO-BASICS
POWER!
solutions
overview
development
operations
24 h
success
Co-located with:
HYDROVISION INTERNATIONAL
Organized By:
HYDRO TRAINING INSTITUTE.

Waterpower.
HYDRO BASICS COURSE
JULY 10-11, 2023 // Charlotte, North Carolina, USA

Waterpower Hydro Basics Overview

Blake D. Rothfuss, PE, D.WRE, P.ENG, M.ASCE
Chief Engineer
Hetch Hetchy Water and Power
City and County of San Francisco

bdrothfuss@sfwater.org
(209) 289.8357

Co-located with: HYDROVISION INTERNATIONAL   Organized By: HYDRO TRAINING INSTITUTE.

Waterpower. HYDRO BASICS COURSE

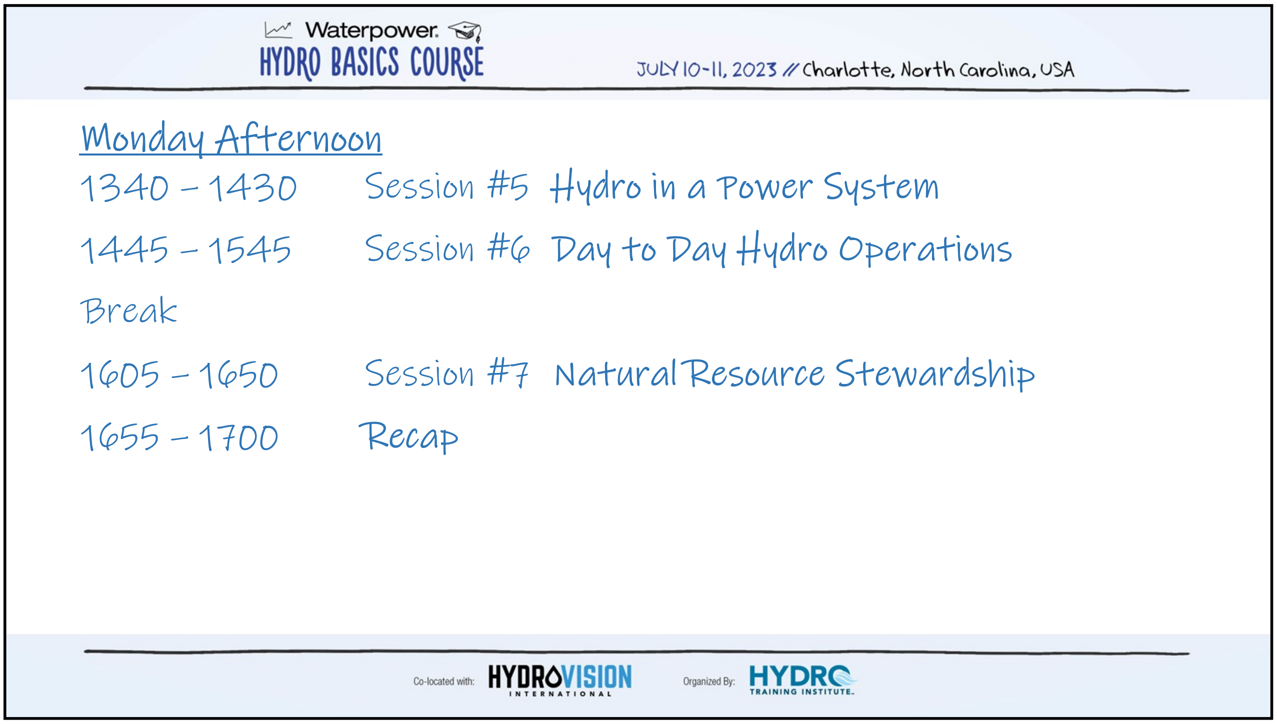
JULY 10-11, 2023 // Charlotte, North Carolina, USA

Monday Morning

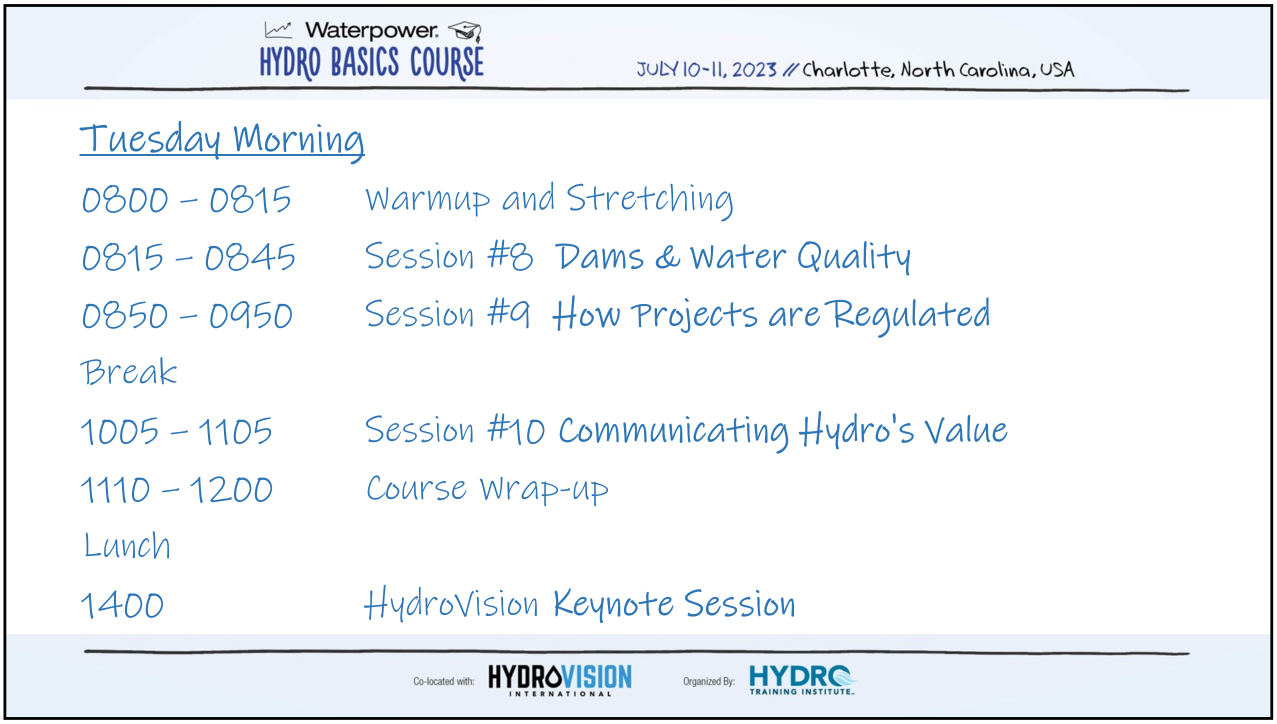
0815 – 0840	Introduction	
0840 – 0900	Session #1	Hydro Overview
0905 – 1005	Session #2	Harnessing the Water
Break		
1020 – 1120	Session #3	Turbine Basics
1125 – 1225	Session #4	Generator & Electrical Sys Basics
Lunch		

Co-located with: HYDROVISION INTERNATIONAL   Organized By: HYDRO TRAINING INSTITUTE

In the classroom, on a computer screen or within the copy of a newspaper story, hydropower is competing with other renewable energy resources for time and space to tell its story.

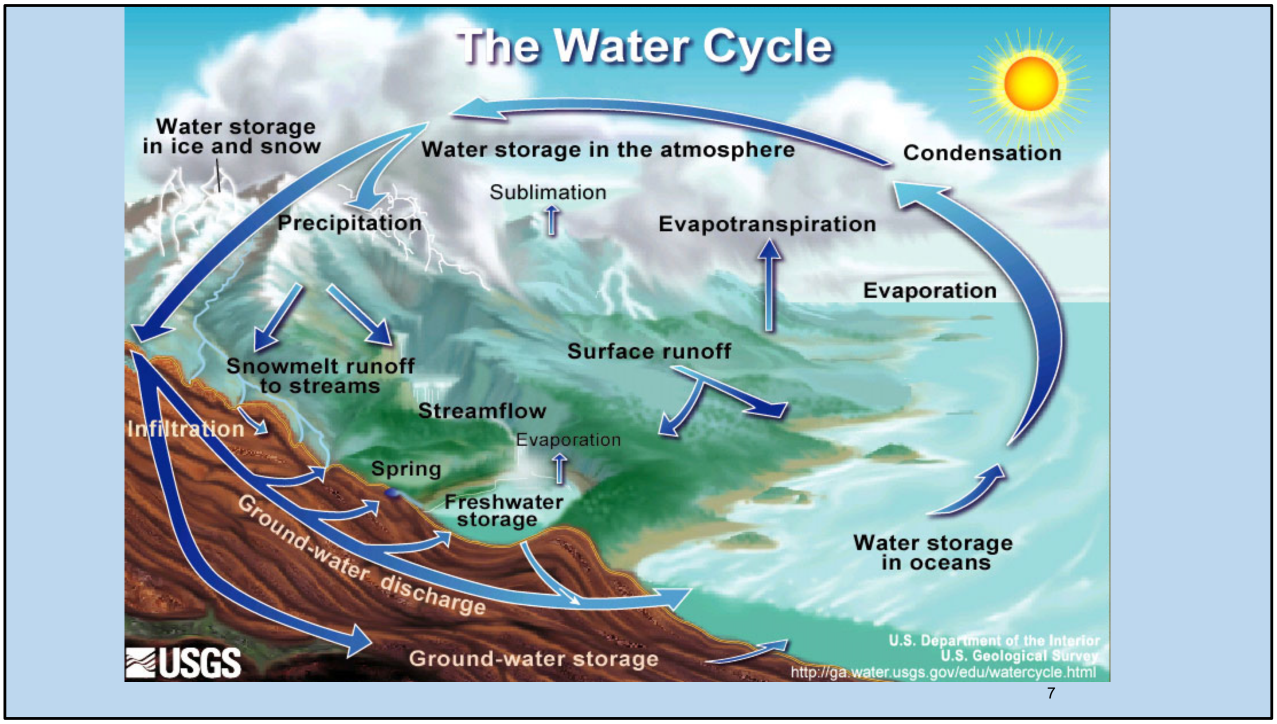


In the classroom, on a computer screen or within the copy of a newspaper story, hydropower is competing with other renewable energy resources for time and space to tell its story.



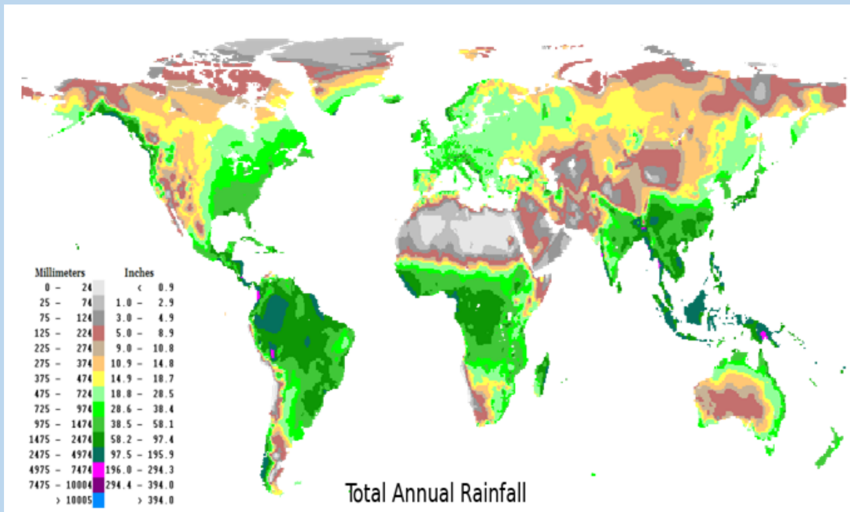
In the classroom, on a computer screen or within the copy of a newspaper story, hydropower is competing with other renewable energy resources for time and space to tell its story.

introduction



Hydro Power is the original solar energy capture.
The sun provides the energy for evaporation of water and for the air pressure differences which push water vapor.
Water vapor condenses at higher elevations and runs back to the sea.
The energy provided by the water at higher elevations can be converted to hydro power.
The wind also produces waves and currents which can also be captured to produce hydro energy.
The sun and moon also create tidal elevation differences in the sea which can be captured to produce energy.

What Nature Gives Us | *Geographic Fuel Variability*



Source: NOAA, rainfall distribution 2010

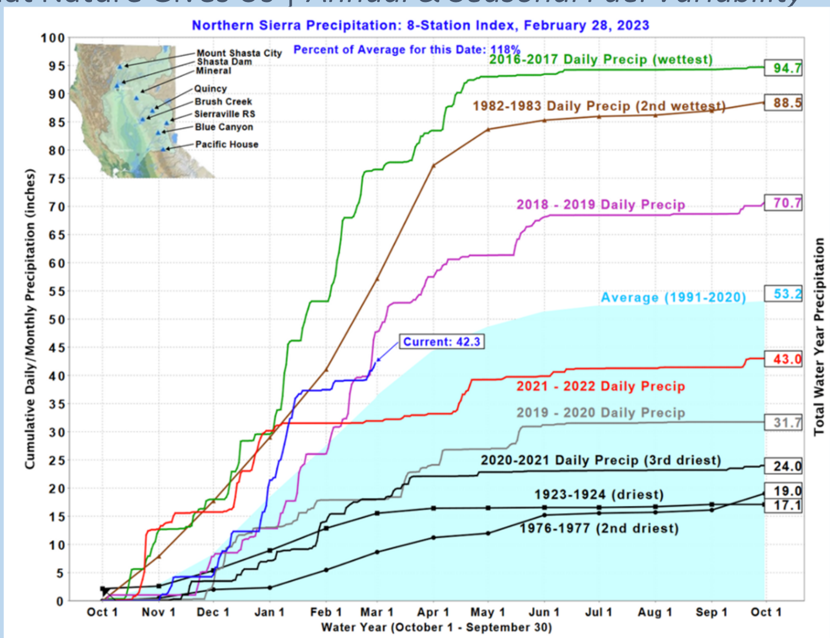
8

Rainfall distributions are not uniform
They are strongly dependent on latitudes, and on local geography.
While basically zonal, they are also quite variable, strongly influenced by ocean temperature driven air currents.

What Nature Gives Us | *Runoff Variability*

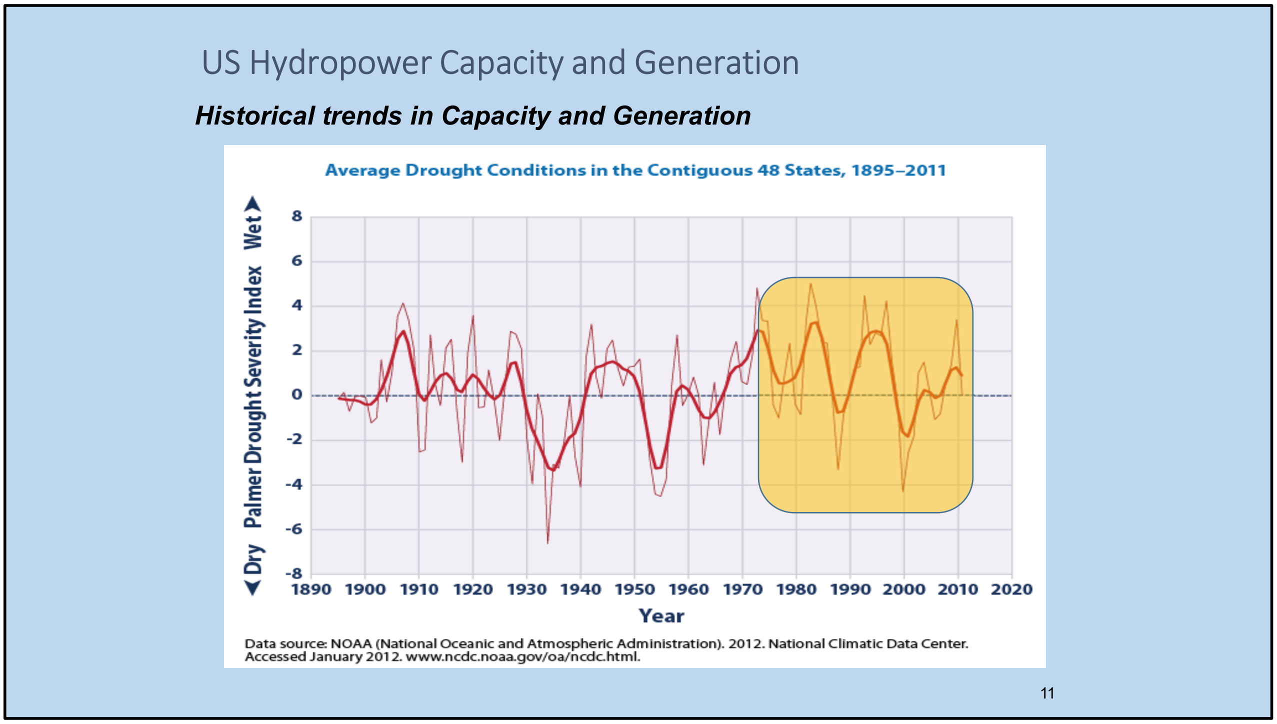
9

What Nature Gives Us | *Annual & Seasonal Fuel Variability*



10

This slide illustrates the dependency of hydroelectric generation on natural cycles of wet-normal-dry seasons

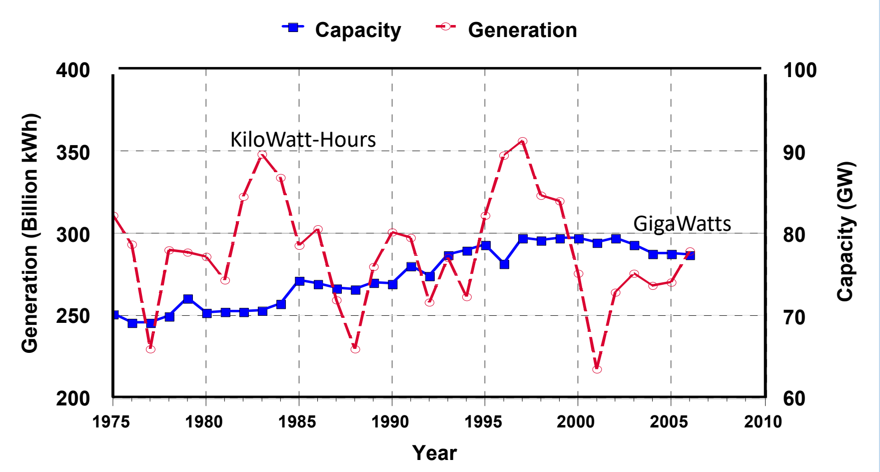


Now, taking a broader view at the influence the wet-dry cycles have on hydroelectric production, we see the US average drought conditions in the Lower 48.

Please note the valleys in the highlighted portion of the graph…. late 1970s, late 1980s, and early 2000s,,, about every 10 years.

US Hydropower Capacity and Generation

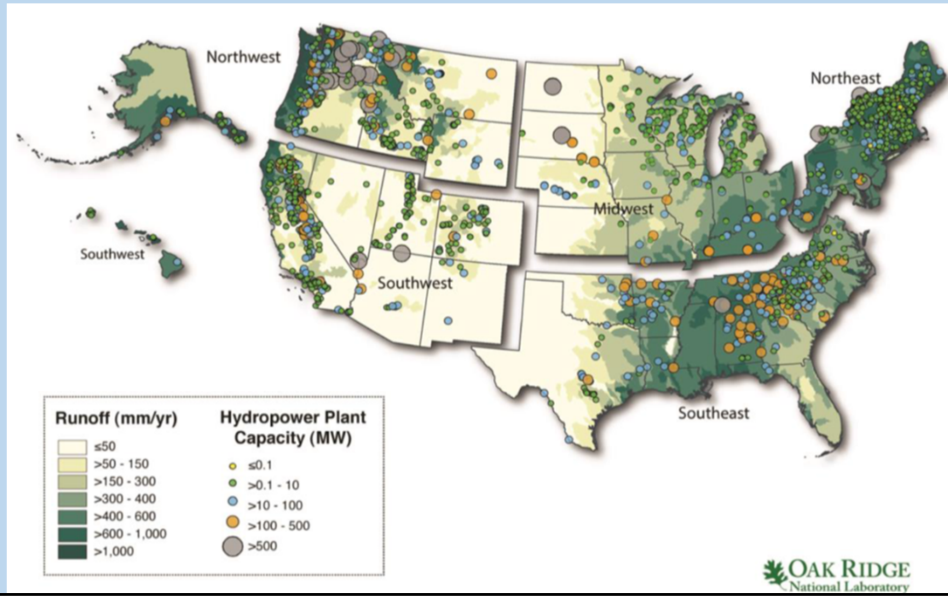
Historical trends in Capacity and Generation



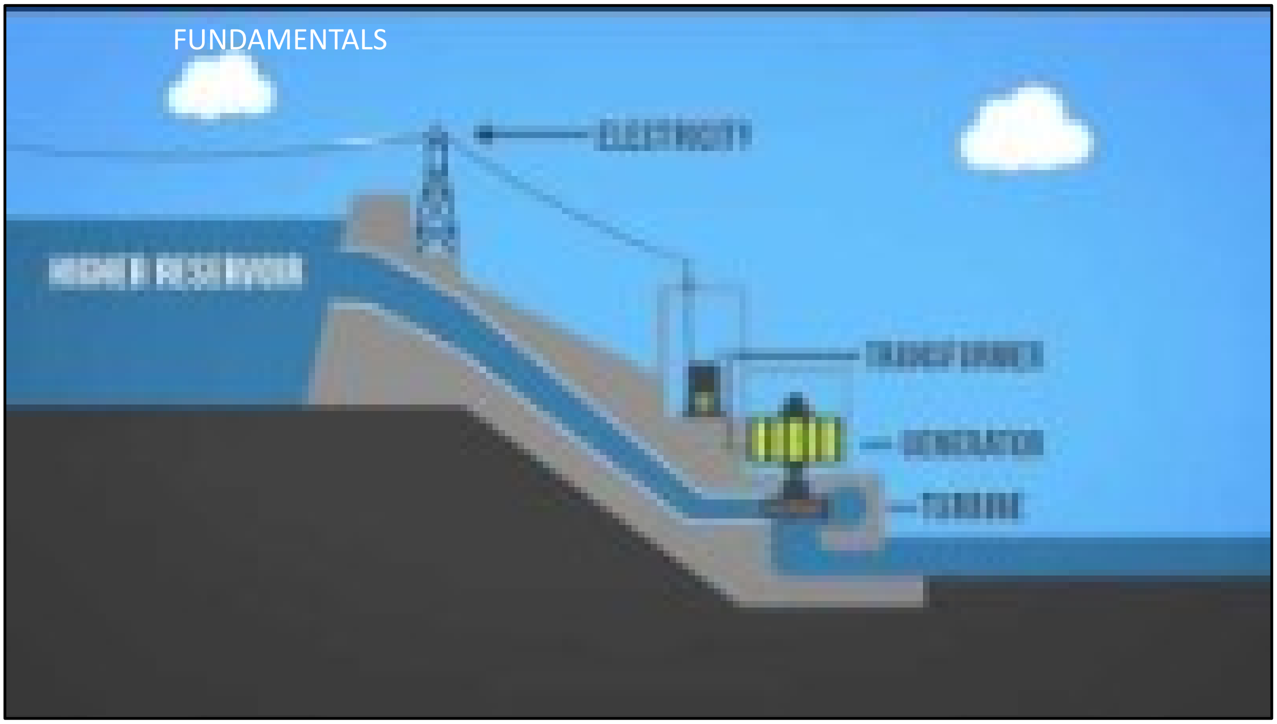
12

Focusing in on the 1975 to 2005 period, we see how generation has similar peaks and valleys. Note that the low generation periods FOLLOW the dry cycle. Also note that although capacity is trending up, increasing by about 10 GW over a 30 year period, hydroelectric generation seems level over the same period.

What Nature Gives Us | *Runoff to Generation*

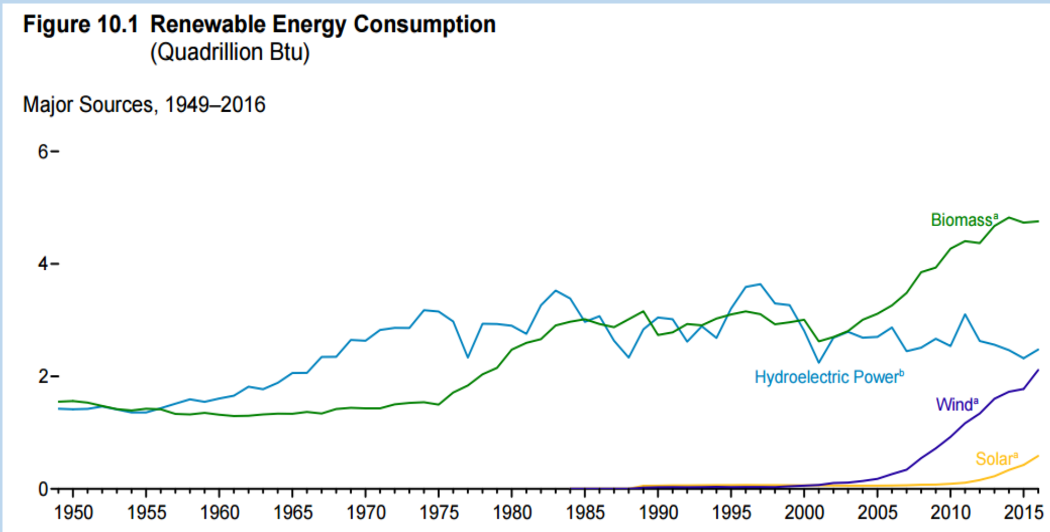


13



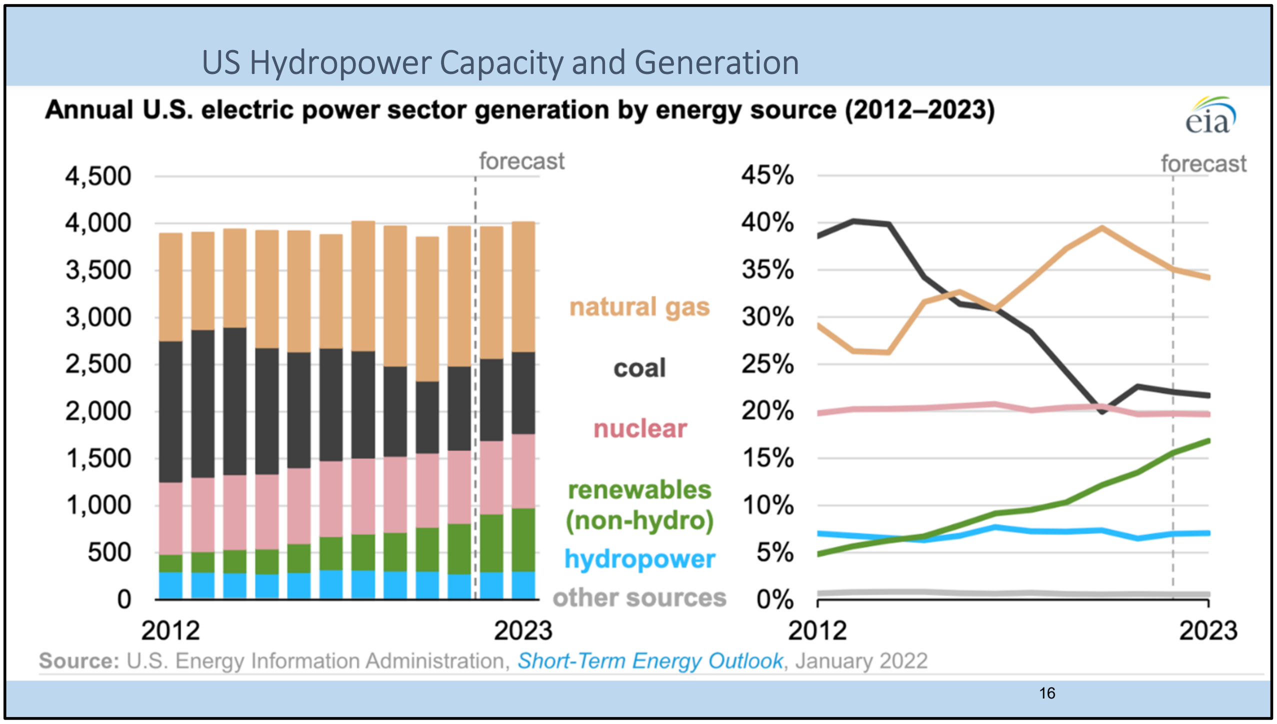
embedded

Major Sources of Renewable Energy



15

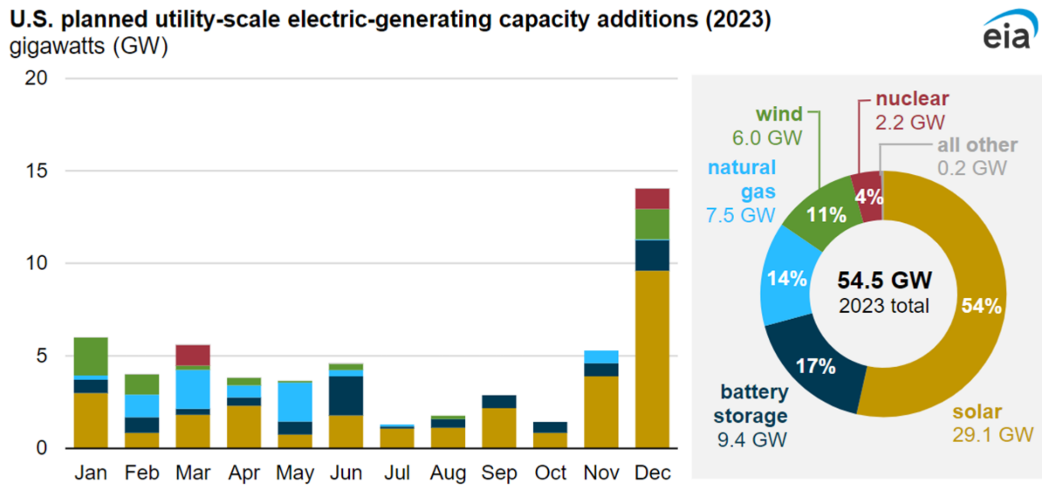
Note the dramatic increase in renewables since 2005.



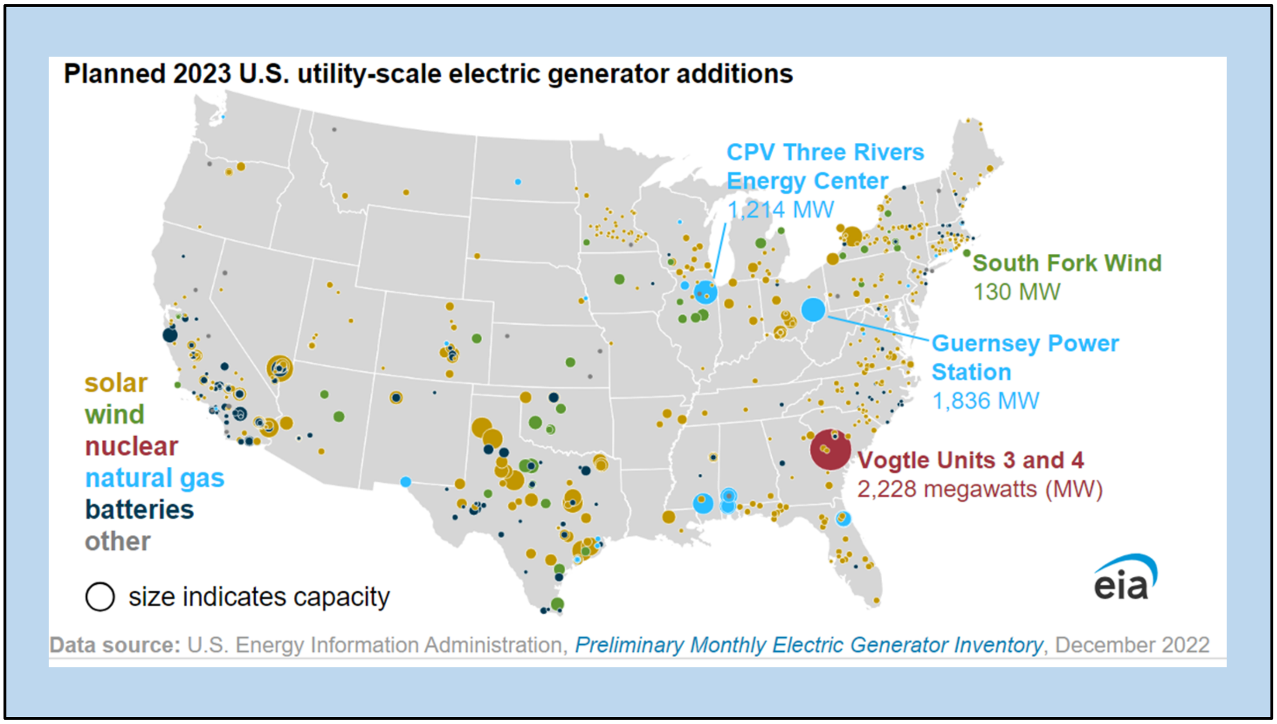
Zooming in on that period, we see that hydropower production has remained more or less level while renewables has increased 6x. What's making up the renewables contribution?

FEBRUARY 6, 2023

More than half of new U.S. electric-generating capacity in 2023 will be solar



Data source: U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory*, December 2022


Planned 2023 U.S. utility-scale electric generator additions
CPV Three Rivers Energy Center
1,214 MW
South Fork Wind
130 MW
Guernsey Power Station
1,836 MW
Vogtle Units 3 and 4
2,228 megawatts (MW)
solar
wind
nuclear
natural gas
batteries
other
size indicates capacity
Data source: U.S. Energy Information Administration, Preliminary Monthly Electric Generator Inventory, December 2022

harnessing the power

How Hydroelectric Power Is Harnessed

- Elevation difference creates head pressure and water motion.
- Created by natural geography or by dams.

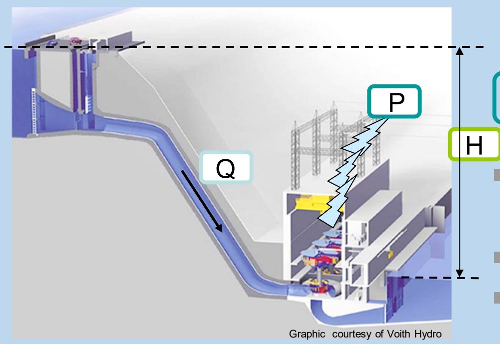
Photo courtesy of Voith Hydro

20

Hydroelectric power potential energy is dependent on elevation differences.
This difference in potential energy drives water flow.
The energy of the flowing water can be captured to produce energy.

Convert the Potential Energy of Water at Elevation to Kinetic Energy Delivered to the Turbine

- Elevation difference (head) creates the water flow
- Turbines are used to convert hydro into electrical energy



Power = f (Head, Discharge, K_L)

- Q, Discharge or flow drives output of the plant
- H, Head drives type of plant
- K_L, energy losses (hydraulic, mechanical, electrical)

21

Power is proportional to head multiplied by discharge.
Discharge characterizes the size of the hydro plant
Discharge is proportional to Head^.5
Consequently, Power is proportional to Head^1.5
Head characterizes the type of plant.

Conventional Hydro

Hoover Dam illustrates a dam-powerhouse configuration in magnificent style. The high head/ high flow powerhouses are in the foreground…. More typical of the western US

Conventional Hydro

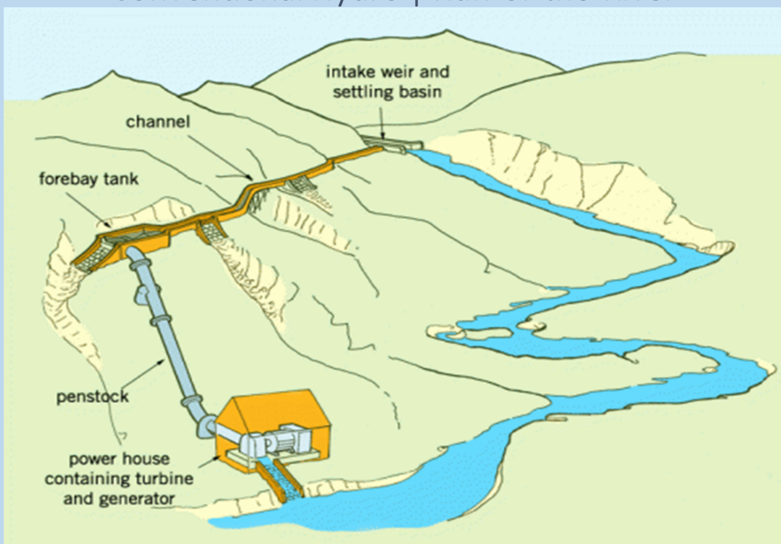
Donnells Reservoir normally operates within a 195 vertical foot range supporting Pelton turbines approximately 8 miles downstream operating under an average net head of 1,238 feet.

Conventional Hydro

24

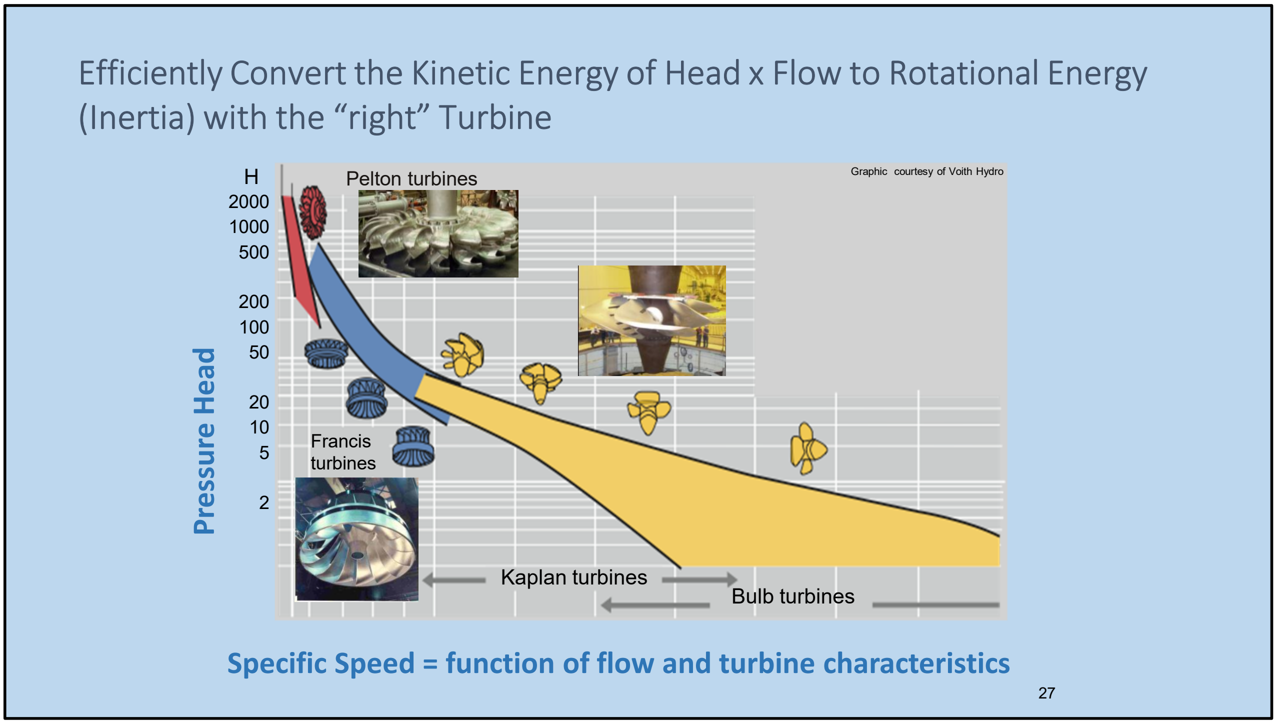
This dam-powerhouse illustrates low head, high flow powerhouse, more typical of the Eastern US

Conventional Hydro | Run-of-the-River



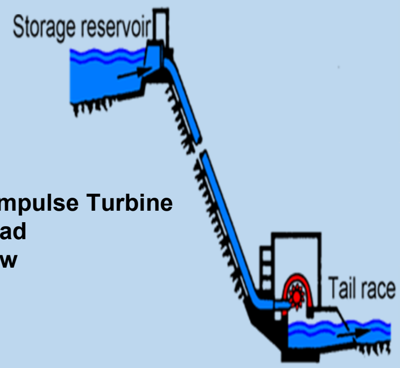
This mid head medium flow powerhouse shows a configuration where the dam and powerhouse are separated by a distance. Water conveyance structures carry the water from the dam to the powerhouse, preserving as much energy as possible.

turbine basics



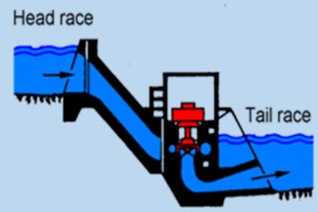
Turbine types are driven by head difference.
High heads – Pelton type. Relatively low quantities of water per MW generated.
Low heads – Bulb type turbines. Low head but relatively high quantities of water per MW generated.
The shapes at the head are based on optimized cost of equipment and plant and are driven by structural and economic issues.

Turbine Types



Pelton or Impulse Turbine
- **High Head**
- **Low Flow**

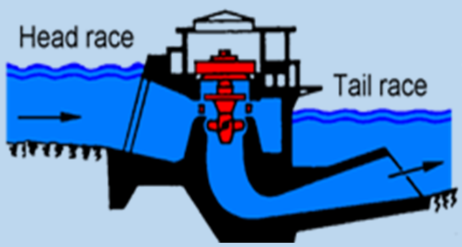
Francis Turbines
- **Mid Head**
- **Mid Flow**

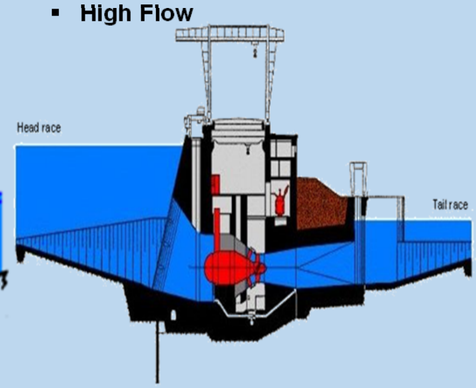


Turbine Types

Vertical Axial Flow Turbines
- **Low Head**
- **High Flow**

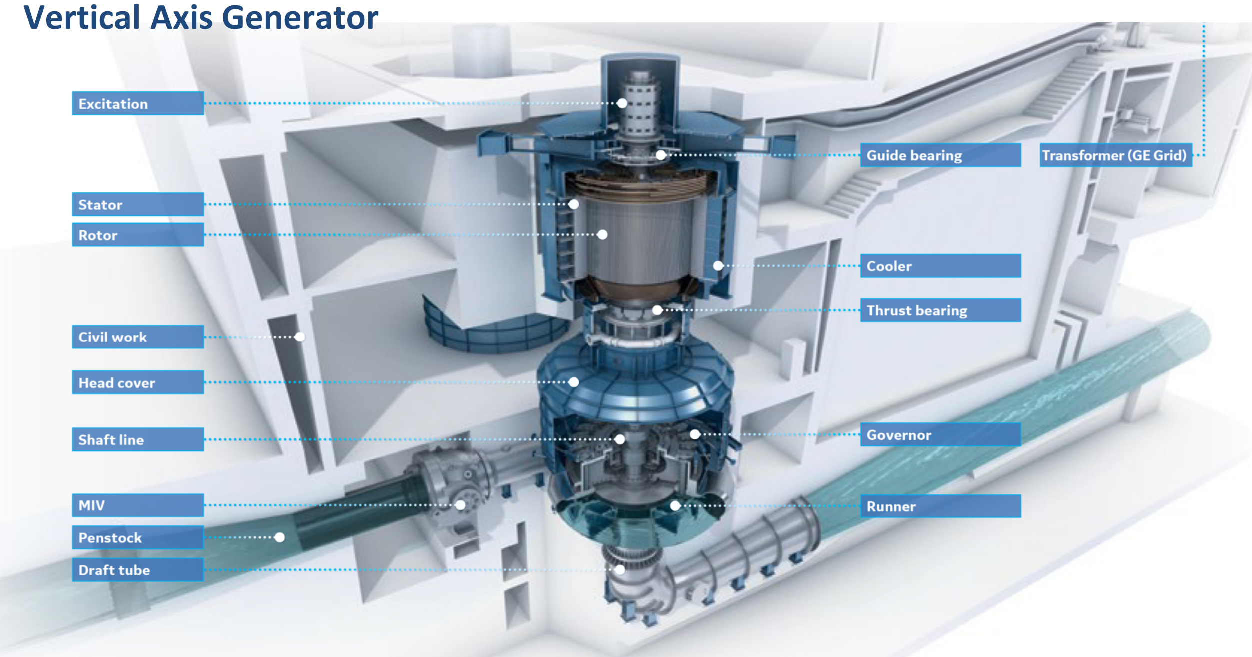
Horizontal Axial Flow Bulb Turbine
- **Low Head**
- **High Flow**



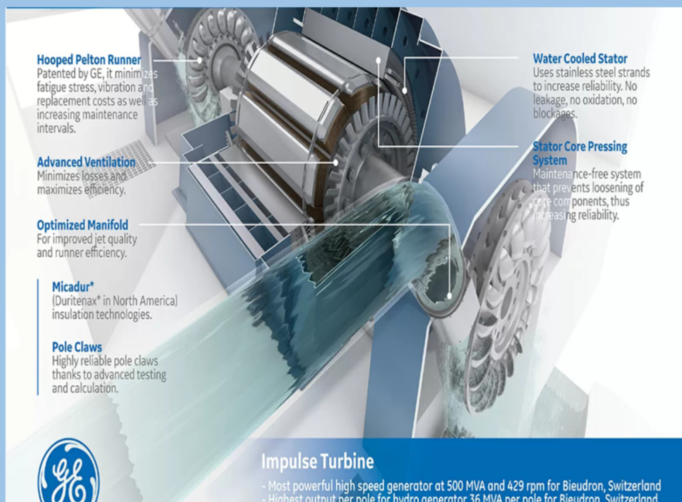


generator/motor basics

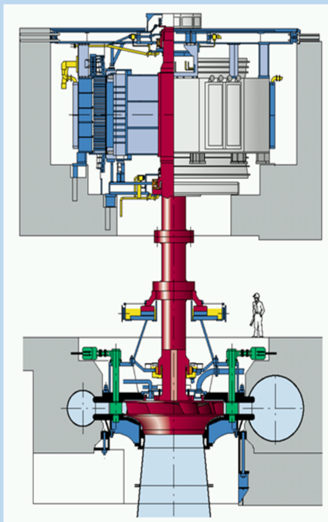
Vertical Axis Generator

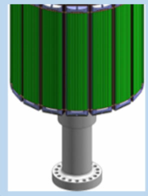


Horizontal Axis Generators

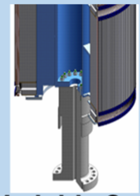


Hydro Pumped Storage
Motor-Generator/Pump-Turbine (typical configuration)





Synchronous Motor Generator Rotor



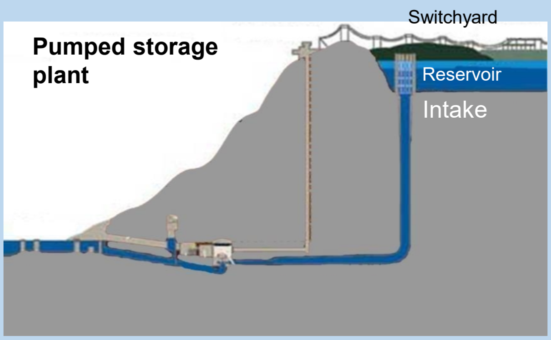
Variable Speed Motor Generator Rotor

Impeller

Photos & Graphics courtesy of Voith Hydro

Single stage reversible machine.
Can be fixed or variable speed.
Variable speed configurations allow power regulation in the pump cycle and wider range of operation.

Hydro Power for Energy Storage
Pumped Storage

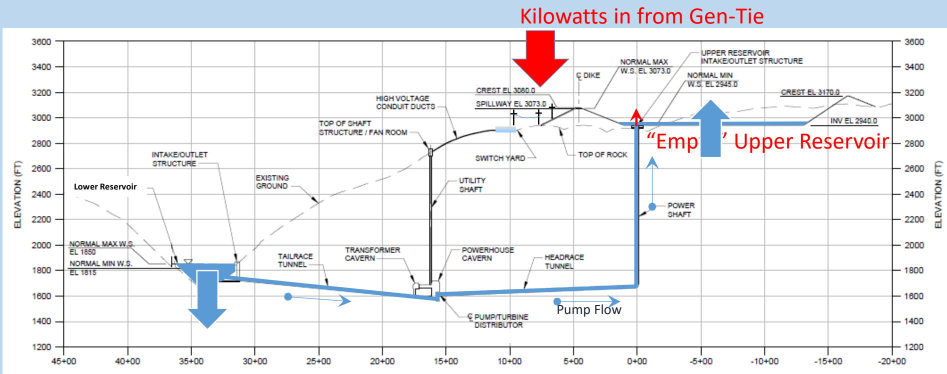


Plant & Reservoirs

34

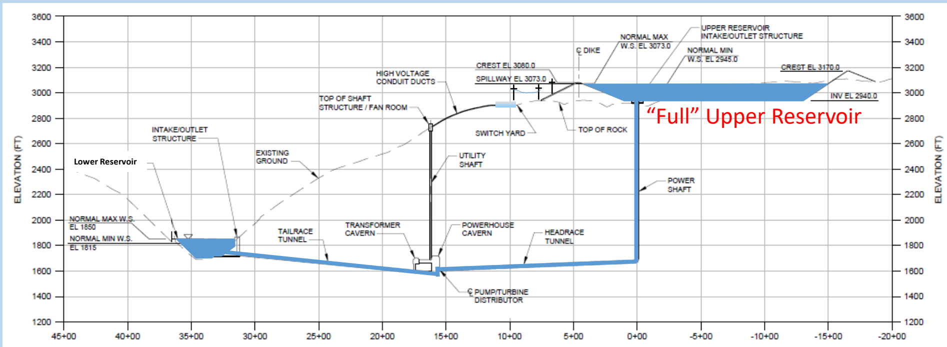
A special use of hydro power is for energy storage.
Either in reservoirs or in a configuration of Pumped Storage.
Pumped storage schemes can use either separate pumps and turbines, or reversible machines.
Pumped storage was developed about 100 years ago.
Had significant surge in the 1950's-80's. Used to work with Nuclear plants.
Nuclear and thermal plants work most efficiently with constant load.
Pumped storage can absorb excess capacity at night and produce peaking energy during the day.
In today's mix of renewables, pumped storage is used to help shift wind and solar energy in time and improve grid frequency characteristics.
The strong growth of renewables is significantly stimulating pumped storage again today, as the wind doesn't always blow and the sun doesn't always shine.
Modern Advanced Pump Turbines are fast responding and can contribute significantly to grid stability.

Operational Schematic | Pump Mode – Beginning of Cycle (1 of 2)

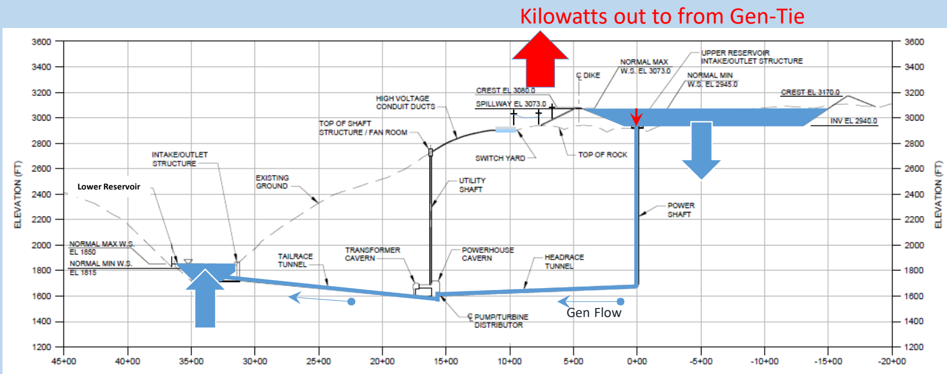


35

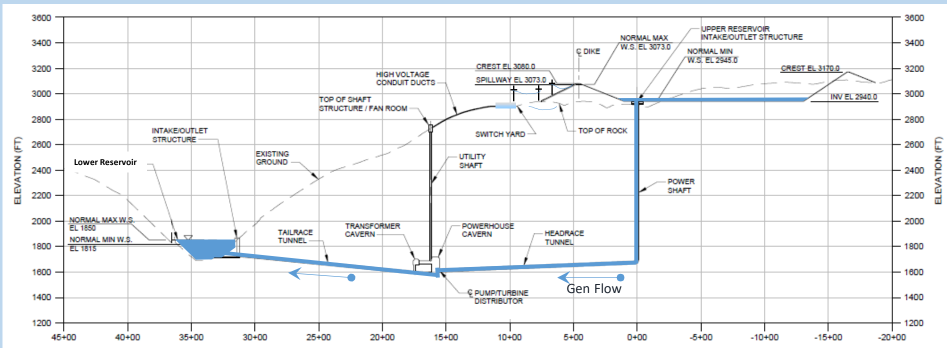
Operational Schematic | Pump Mode – End of Cycle (2 of 2)



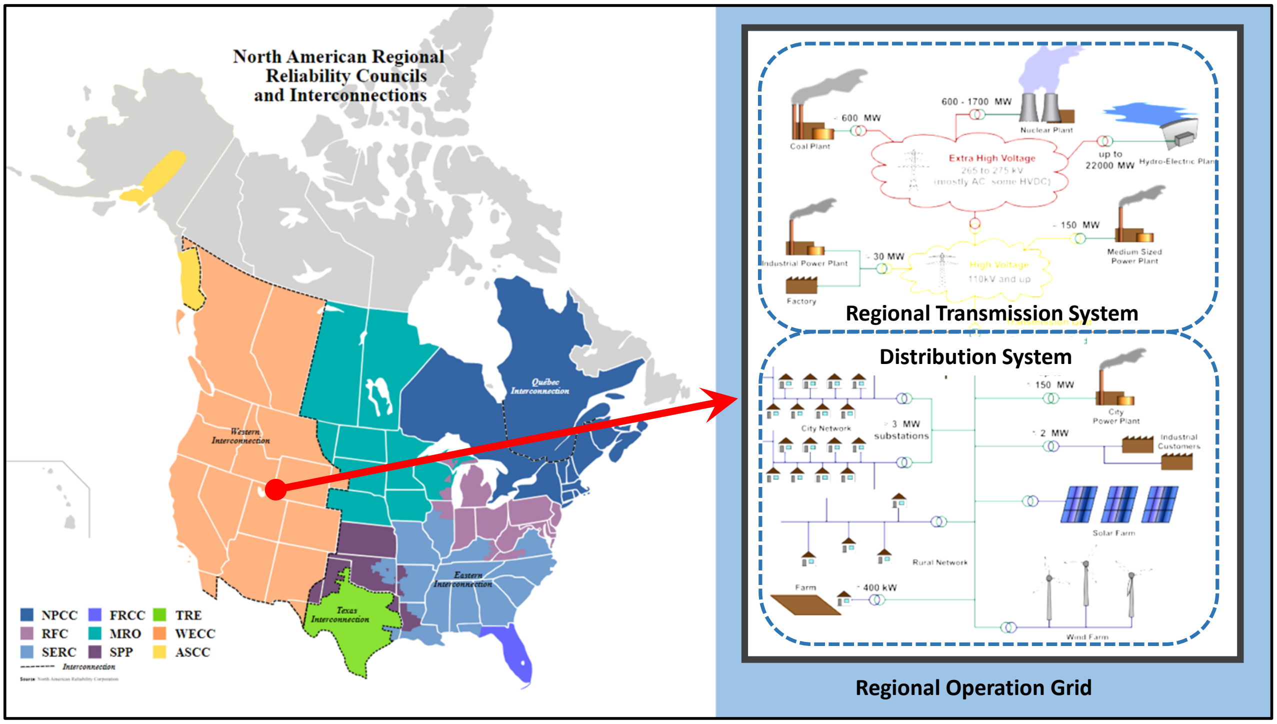
Operational Schematic | Generation Mode – Beginning of Cycle (1 of 2)

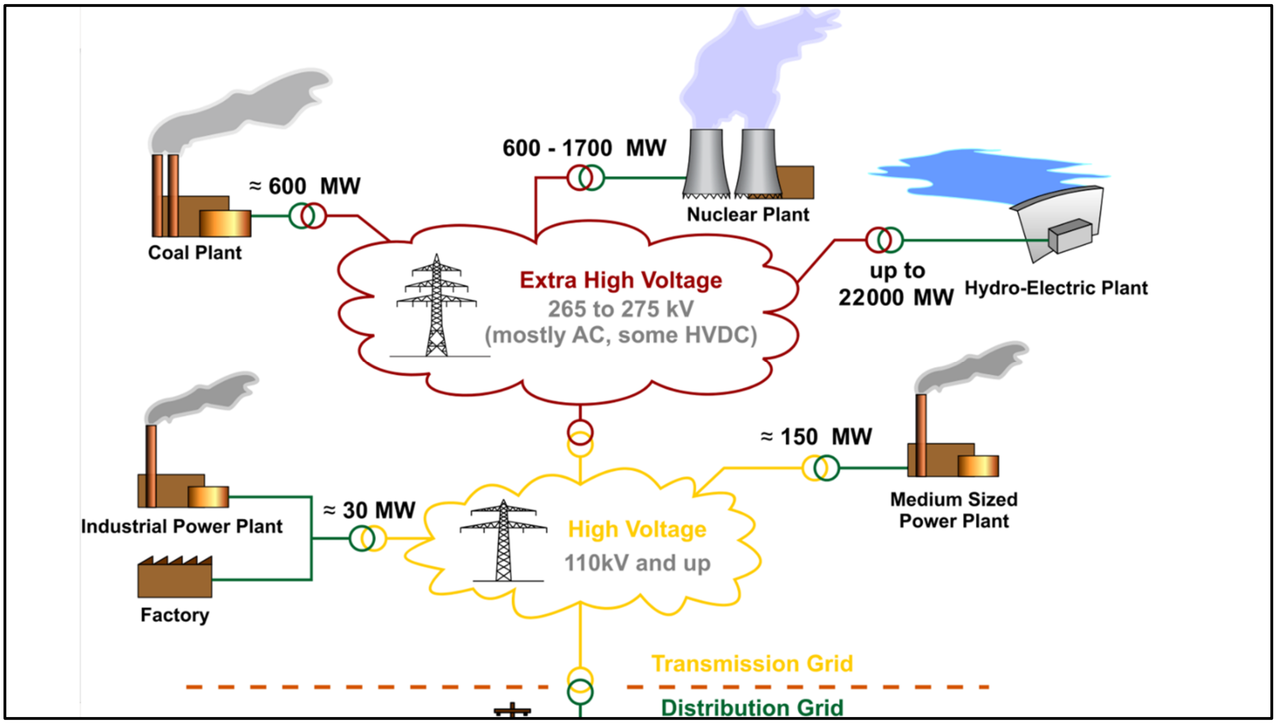


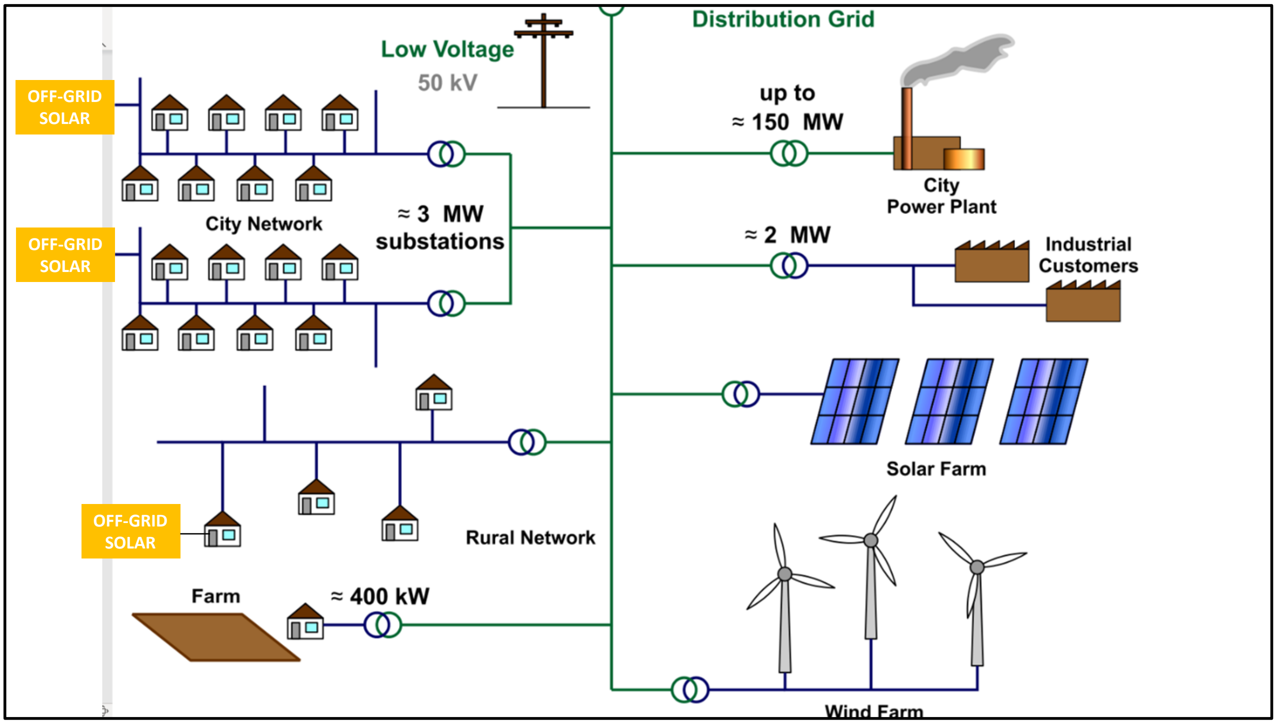
Operational Schematic | Generation Mode – End of Cycle (2 of 2)



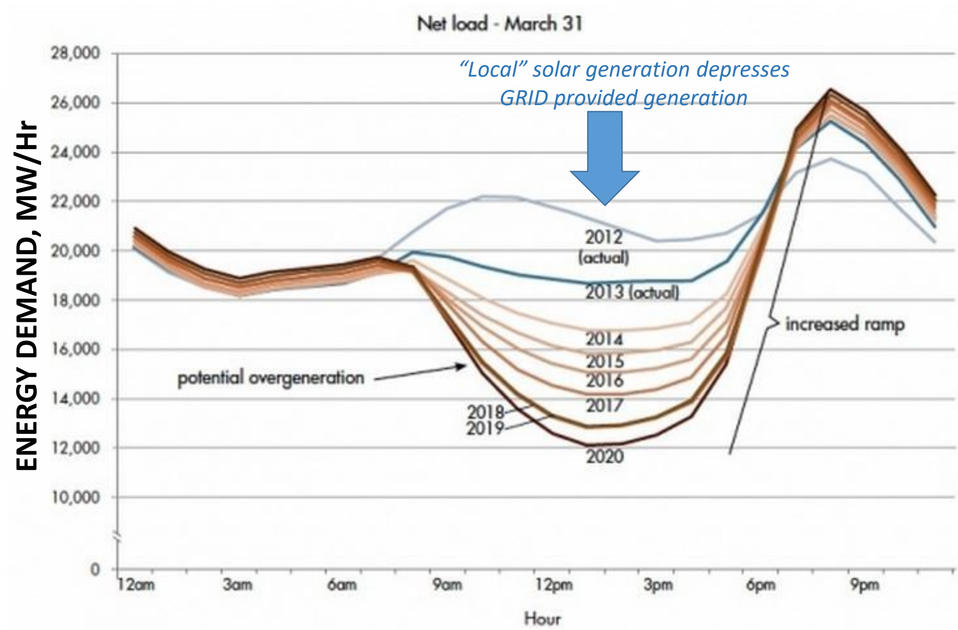

daily operations & power grid basics


North American Regional Reliability Councils and Interconnections
Western Interconnection
Québec Interconnection
Eastern Interconnection
Texas Interconnection
NPCC
FRCC
TRE
RFC
MRO
WECC
SERC
SPP
ASCC
Interconnection
Regional Transmission System
Distribution System
Regional Operation Grid


600 - 1700 MW
≈ 600 MW
Coal Plant
Nuclear Plant
Extra High Voltage
265 to 275 kV
(mostly AC, some HVDC)
up to
22000 MW
Hydro-Electric Plant
≈ 150 MW
Medium Sized
Power Plant
Industrial Power Plant
≈ 30 MW
High Voltage
110kV and up
Factory
Transmission Grid
Distribution Grid


Distribution Grid
Low Voltage
50 kV
OFF-GRID SOLAR
OFF-GRID SOLAR
OFF-GRID SOLAR
City Network
≈ 3 MW
substations
up to
≈ 150 MW
City
Power Plant
≈ 2 MW
Industrial
Customers
Solar Farm
Rural Network
Farm
≈ 400 kW
Wind Farm

The Duck Curve: What is it and what does it mean?



Energy Alabama. 2017.05.29.

The duck curve, explained.

As you can see, this chart shows the electric load of the California Independent System Operator (ISO), just think the California grid, on an average spring day. The lines show the net load—the demand for electricity minus the supply of renewable energy—with each line representing a different year, from 2012 to 2020. The chart also shows that energy demand reaches its peak in the morning (between 6 A.M. and 9 A.M.) and afternoon times (between 6 P.M. and 9 P.M). This demand shows that people need more energy as they get prepared for work or school in the morning and when they come home from work or school in the afternoon.

Let's look at lines 2012 and 2017, for example. Comparatively, the 2012 line is much more smoother than the 2017 line. This is because the feed of a renewable power supply has not yet been introduced. By slowly integrating solar energy, the demand for electricity from the electrical grid becomes smaller and smaller. However, the renewable energy source is not enough to meet the demand in its entirety, especially in those peaks hours that I referenced earlier. So the electric grid is left to pick up the slack, which can sometimes be problematic.

Why is a duck causing problems?

As you can see by the chart, solar energy works best during the bright hours of the day, which makes energy demand lower greatly. We'll call this the duck's belly: the lowest point of demand. The demand begins to rise rapidly as the sun sets and people get home at 6 P.M. There’s no sun to power all of the appliances getting turned on by people returning home from work or school, and the grid is left to answer to that high demand. Therefore, the demand rises very rapidly (the duck’s neck) to a peak in the afternoon hours (the duck’s head).

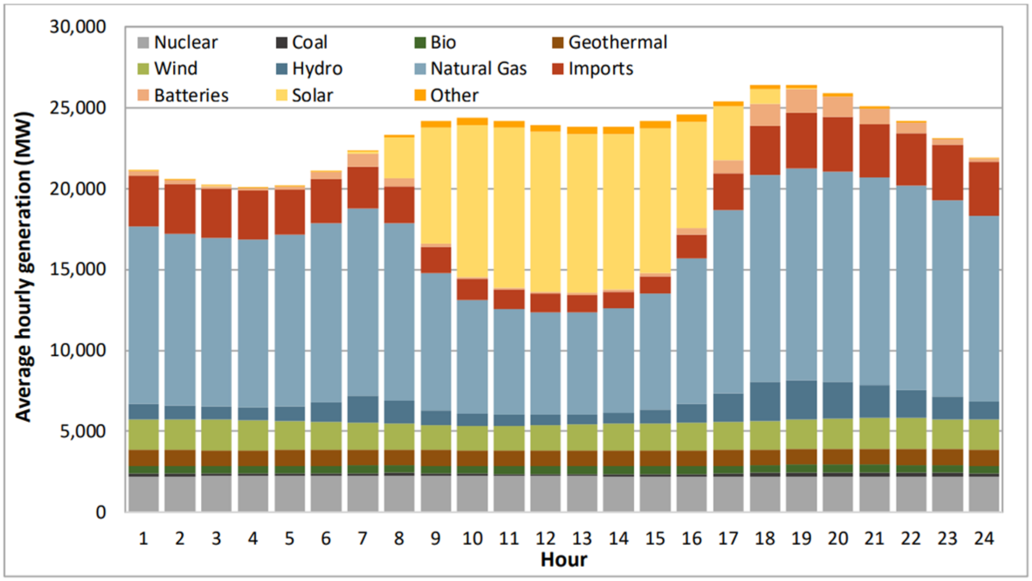
For many decades, energy demand followed a fairly predictable pattern, with very little change in levels of demand. This allowed electrical workers to become experts with sustaining a stable output of energy. Well the duck curve kinda throws a wrench in that. In order to meet the baseline requirement, or “baseload”, utilities run BIG power plants that run on either nuclear or coal, which run around the clock. The problem with coal and nuclear power plants is that they’re expensive to completely startup and shutdown, and are more effective in ramping up or down. Then there’s the “peak load,” which is satisfied by peaker plants that usually run on natural gas, and more frequently renewables.

In order to maintain top efficiency, regulators will often turn peaker power plants off and ramp down the baseline plants during times of very low demand, such as hours of the “duck’s belly.” However, the sudden and rapid increase in demand means that regulators have to quickly turn back on these power plants, which is not only expensive, but could lead to more pollution and high maintenance costs.

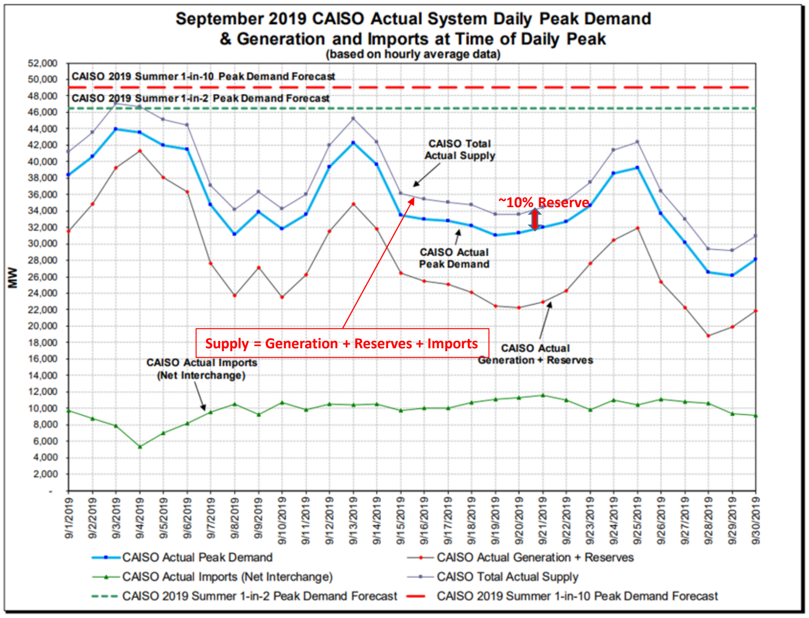
Another problem with the duck curve lies in the belly of the duck. In some places, demand becomes so low that grid operators are forced to turn off the peaker power plants and ramp down the baseline power plants. Then, just a few hours later, they all have to get ramped up again with little to no warning, which can cause problems for grid stability.

So problems with the duck curve lie in those sudden and steep changes in demand. Grid operators and regulators struggle to maintain stability and efficiency by turning power plants on and off, causing instability in the power supply, large expense to taxpayers, and pollution to the environment.

Figure 1.4 Average hourly generation by fuel type (Q4 2022)



Appendix A: 2019 Summer Supply and Demand Summary Graphs



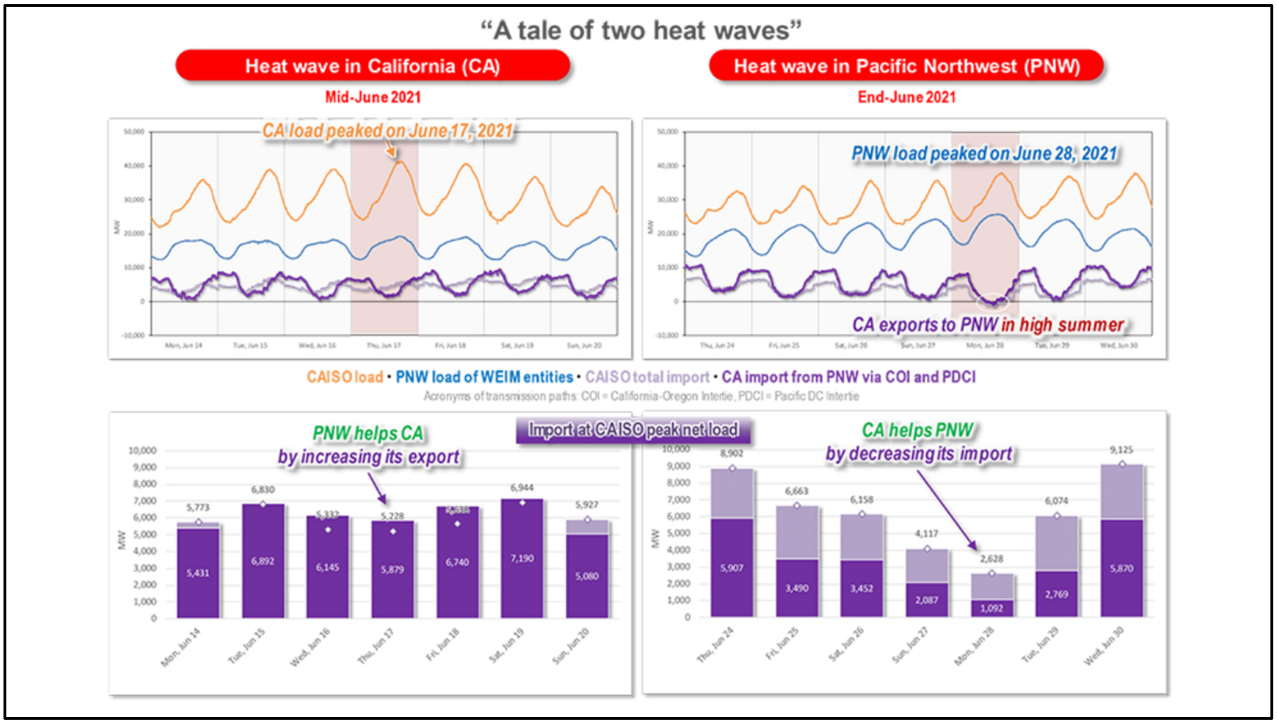
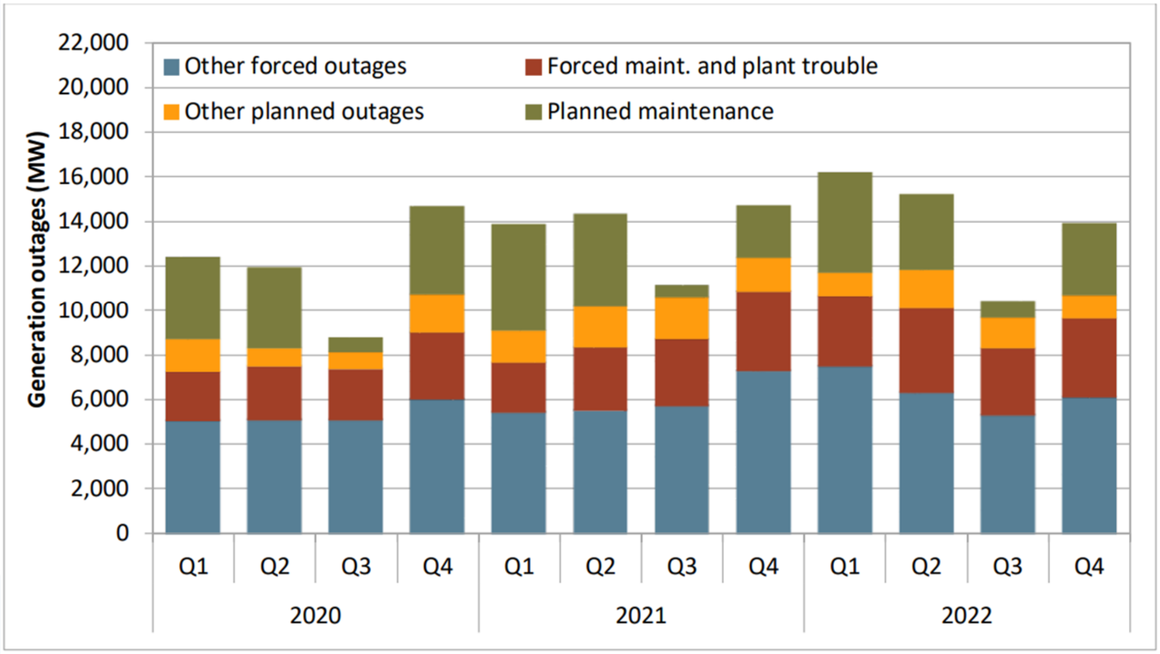

"A tale of two heat waves"
Heat wave in California (CA)
Mid-June 2021
Heat wave in Pacific Northwest (PNW)
End-June 2021
CA load peaked on June 17, 2021
PNW load peaked on June 28, 2021
CA exports to PNW in high summer
CAISO load • PNW load of WEIM entities • CAISO total import • CA import from PNW via COI and PDCI
Acronyms of transmission paths: COI = California-Oregon Intertie, PDCI = Pacific DC Intertie
PNW helps CA by increasing its export
Import at CAISO peak net load
CA helps PNW by decreasing its import

Figure 1.7 Quarterly average of maximum daily generation outages by type – peak hours



stakeholder basics

Multiple Uses / Multiple Benefits

Dams and Reservoirs provide other attributes than power

Flood / Storm Control

Navigation

Water Supply & Drought Mitigation

Irrigation

Recreation

49

Dams and Reservoirs provide other attributes than power.

Some of these, like water storage for drinking water have values as high or higher than that of power generation.

The recreational values are perceived as quite high by users.

Environmental Considerations

- **Fish Passage**
- **Instream Flow Releases**
- **Water Quality -- Dissolved Oxygen, Temperature, Turbidity**

50

Hydropower is generally perceived as green and renewable energy.
There are however a number of "tarnishes" on hydro's image.
In the US, these include:

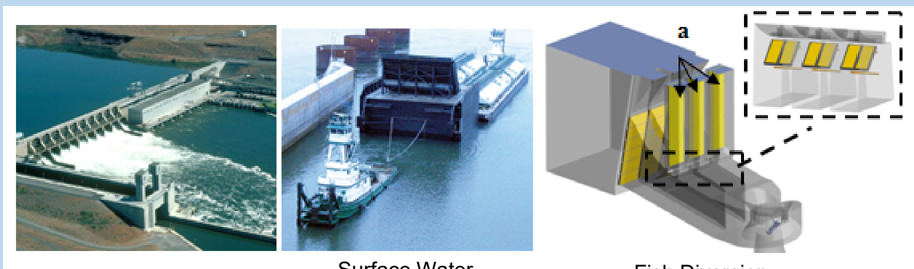
Fish Passage
Dissolved Oxygen
Oil Free
Minimum Stream Flow

Additionally, issues associated with displacement of people when new reservoirs are built also create a lot of concern from environmentalists.
Finally, reservoir emissions (methane, CO_2) from decaying vegetation are also a source of environmental concerns.

Environmental concerns are key factors in licensing.

Fish Passage

- Hydroelectric dams can impede migrating fish.
- Several methods are used to divert fish around the turbines.



Spilling | Surface Water Collector | Fish Diversion Screens

51

Fish Passage is a key issue in many portions of the US.
Salmon fish passage is a very large concern in the Pacific Northwest.
Fish survival concerns are spreading through the US and the World.

Key Factors Influencing Survival

Reducing Fish Entrainment

- Escapable approach velocities
- Inlets positioned in lower fish density zones
- Use fish-friendly deterrents and screening systems

Reducing Fish Injuries

- Consider fish size when designing turbine
- Require smooth concrete and steel surfaces
- Improving water quality (DO)

52

Fish injury due to mechanical effects (strike, grinding, scraping)

- Number of blades, vanes
- Size of fish and turbine
- Surface roughness
- Fish location zone

Fish injury due to fluid effects

- Flow turbulence or shear (efficiency, operation)
- Pressure
- Cavitation
- Fish location

Dissolved Oxygen Enhancement

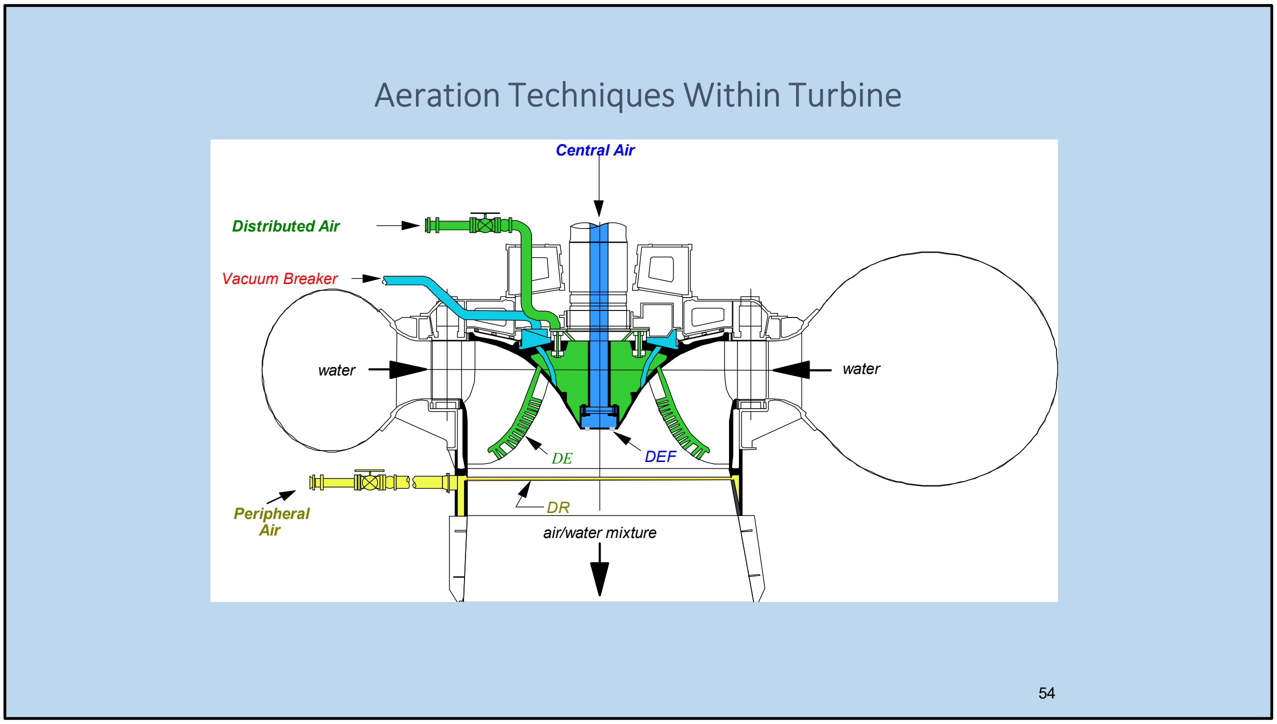
Aration improves water quality by increasing DO levels

- air introduced into the water passing through turbine

- two-phase mixture causes oxygen to pass from higher to lower concentration (gas to liquid)
- Restore tailrace DO levels to 4-6 mg/liter

53

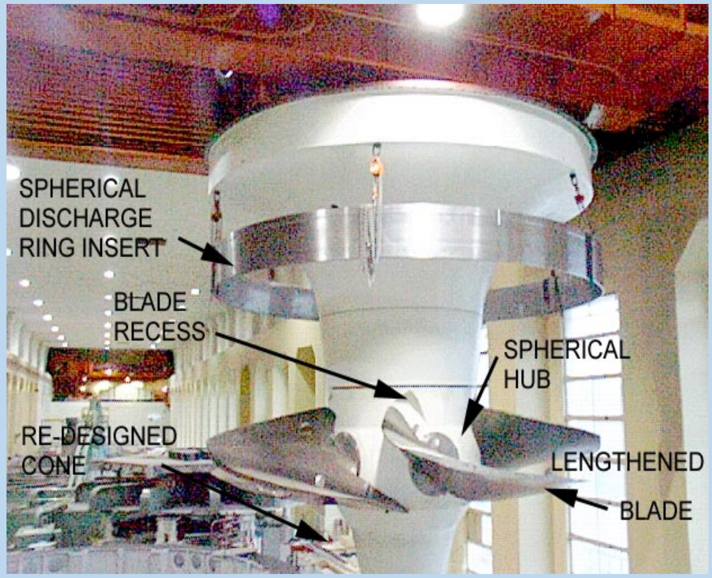
Aeration can be done upstream of the dam by mixing water elevations, or by bubbling O_2 into the water.
Or downstream of the dam by using weirs in the discharge.
But the most cost efficient solutions are usually found by using the turbines to implement aeration.



Special turbine designs have been developed to re-aerate the water and increase the dissolved oxygen levels.
These turbines can also remediate low DO levels caused by point sources of pollution such as through discharge of sewage from cattle feed lots into the waters, or discharge of organic matter such as paper mill effluent.

Advanced Fish Friendly Turbine

Conventional Design

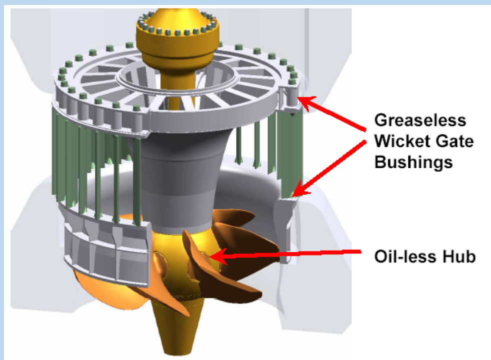


55

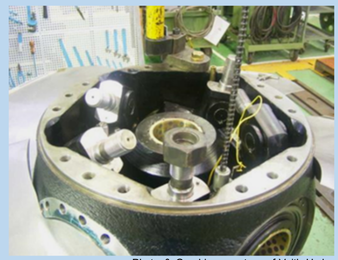
Since 1995, a series of studies have been focused on improving turbine design to improve fish passage survival.
Two significant projects have been undertaken to implement improved Kaplan turbine designs through modernization.
Bonneville Dam has had the turbines of the first powerhouse modernized with minimum gap turbine designs with improved fish survival noted.
Wanapum Dam is undergoing modernization. There, turbines have been modernized to increase power generation significantly while keeping the fish passage survival at a high level.
MGR stands for “minimum gap runner” and signifies a design where the blades of the turbine are fully enclosed
by a spherical discharge ring and a spherical hub, providing a small constant gap as blades are adjusted from minimum to maximum blade pitch.

Oil Free Turbines

Oil-less and greaseless designs can be combined with Fish Friendly Kaplan turbines to reduce water contamination.



Oil-less water filled Kaplan hub

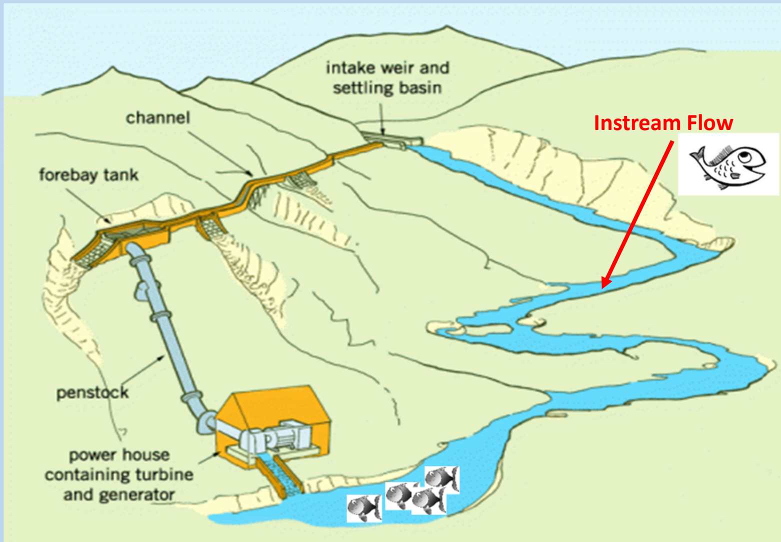


Photos& Graphics courtesy of Voith Hydro

56

Oil has been used for servomotor pressure actuation.
Also grease has been used for lubrication.
Modern turbine designs are increasingly utilizing oil-free and grease-free design concepts.

Instream Flow

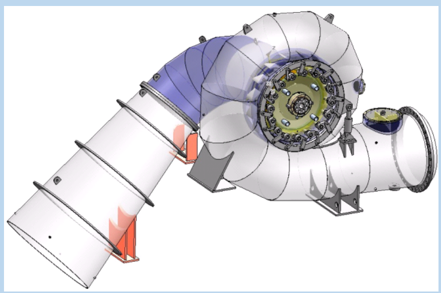


57

This mid head medium flow powerhouse shows a configuration where the dam and powerhouse are separated by a distance. Water conveyance structures carry the water from the dam to the powerhouse, preserving as much energy as possible.

Minimum Stream Flow

- Some multi unit plants have had one unit redesigned to pass much smaller flows.
- Others utilize small standardized units for cost effective solutions




Photos& Graphics courtesy of Voith Hydro

58

Because hydro plants are called on to regulate power in the grid systems, there are times when hydro plants are used to store energy.
At those times little water is discharged through plants.
Too little water is harmful to aquatic habitats downstream of the plants, so minimum stream flow quantities of discharge have been established for plant operations.
In plants where only large turbines exist, operation of the large turbines at low levels of output is detrimental to turbine structures.
Use of minimum stream flow turbines can help the provide the minimum flows.
These minimum flow turbines can also be designed as aerating turbines.

emerging opportunities

Developing Hydropower Technologies

Ocean / Tidal

- Wave
- Current
- Thermal

In Stream

- Current

60

In an introduction into hydropower basics, one also needs to mention the new technologies which are emerging.
Those include ocean wave, current, and ocean thermal energy sources which are being investigated and also in stream sources of energy present in flowing water in rivers and canals.

Developing Hydropower Technologies

Tidal Dam

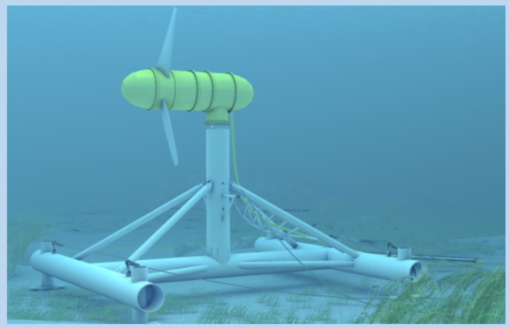
- Sea water flows into (and out of) a natural basin
- Dam creates head
- Classical hydro technology

61

Tidal energy can be harvested through tidal dams and turbines to capture the energy as head energy.
Conventional hydropower technologies (respecting the salt water corrosion issues) can be used.

Developing Hydropower Technologies

Tidal Current
- Kinetic energy of the periodically returning tides is harvested
- Tidal current plant is a dam-free
  free-flow hydro power plant



Graphics courtesy of Voith Hydro

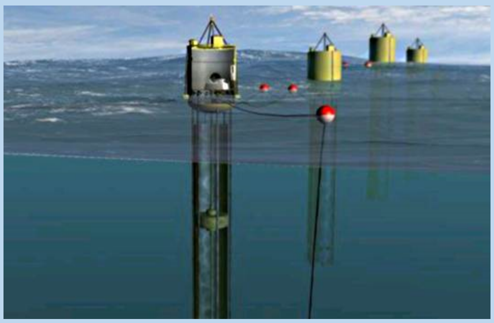
62

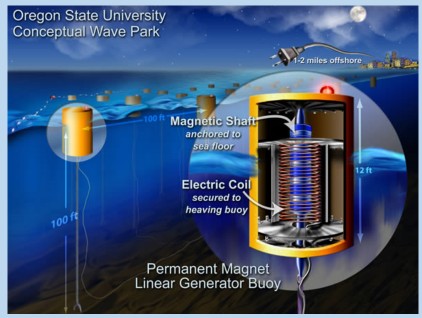
Currents produced by tides can be used.

Developing Hydropower Technologies

Wave

- Wave motion - buoy





Courtesy *Aquabuoy* system

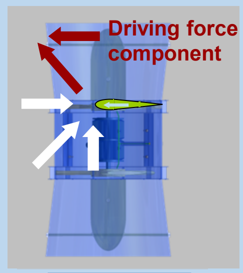
63

Energy in waves can be harvested, for example with these wave elevation capture devices.

New Hydropower Technologies

Wave

- Wave surge compressing air as it runs through air turbine



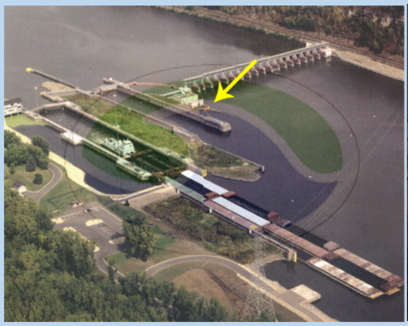
64

Or with these wave energy capture devices.

Developing Hydropower Technologies

In Stream / Hydro Kinetic

- Kinetic energy of the current is harnessed



Courtesy of Hydro Green Energy, LLC

Project at Hastings, MN Hydro+™,

65

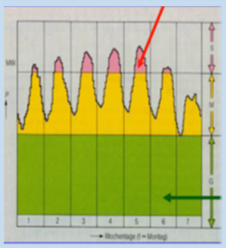
In stream energy capture, or hydrokinetic, devices are also being evaluated.

Current Issues – The Grid

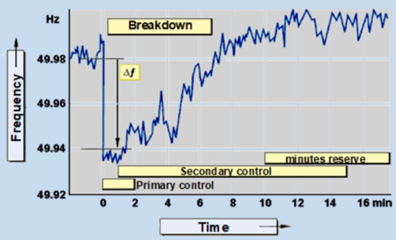
Wind, Solar and Hydro Integration

When the wind is not blowing or the sun is not shining, pump storage can act as a large battery.

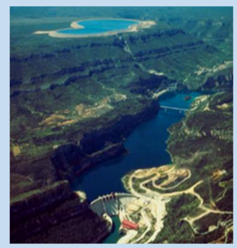
- Reserves
- Frequency regulation



Energy



Frequency

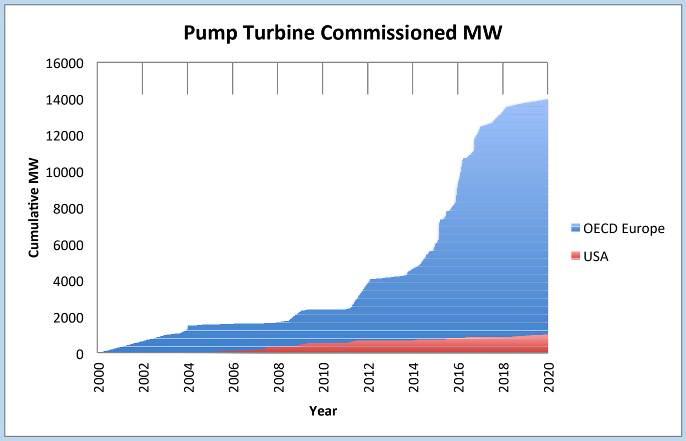


Storage

66

#3: With the rapid growth of wind and solar energy, issues of "grid" stability are surfacing.
Hydro is being called upon to play an increasingly important role to "buffer" the impacts of wind and solar energy production.
Here, hydro's ability to quickly provide or reduce (absorb) power is key.
The realization that pumped storage can help stabilize the grid is growing in the US.
In Europe, with its relatively high wind energy production, pumped storage schemes for fast energy changes are growing rapidly now.

Pumped Storage Growth, U.S. vs. Europe



67

Wind and Solar energy as a % of total energy in Europe is higher than U.S.
In Europe, PS is used to help integrate intermittent renewable energy (wind and solar)
In U.S. gas turbines play that role at the moment.

Pumped storage growth in Europe is much higher than in US.

wrap-up

Google

california electric car mandate

News | End | Images | Videos | Shopping | Books | Maps | Flights | Finance

About 7,940,000 results (0.41 seconds)

Yes. California is only requiring that all NEW cars sold in 2035 and beyond are zero-emission vehicles which includes battery electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles.

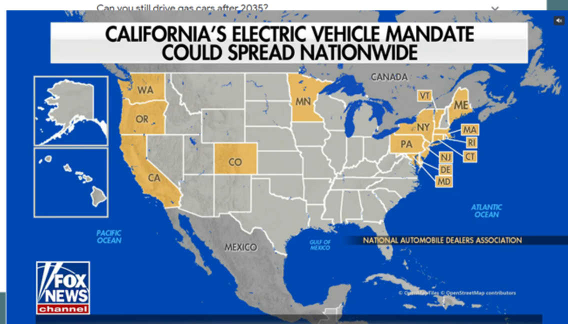
CA.gov
https://ww2.arb.ca.gov › resources › documents › cars-a...

Cars and Light-Trucks are Going Zero - Frequently Asked ...

About featured snippets · Feedback

People also ask

Is California outlawing electric cars?



HOUSING

California Ban on Gas Appliances Starts With Jan. 1 'All Electric' Rule

Published 7 months ago on December 16, 2022
By Nancy Price, Multimedia Journalist

(AP File Photo)

We're going to need more

We're Gonna Need…

Increased hydro capacity meeting future demand by

- ***upgrading existing hydro stations and leveraging existing infrastructure***
- ***Increasing unit availability by decreasing unit forced outages and planned maintenance outage durations***

Increased energy storage capacities by

- ***recognizing the economic value of pumped-storage hydro storage/ancillary services and high-capacity battery lifecycle***

Faster reacting generators and turbine by

- ***integrating technology and machine design***

Faster reacting electric grid protection systems by

- ***installing faster cyber-secured communication systems and devices***

With the use of hydro to provide large load changes quickly and frequently, the loading of the components of the hydro plant are increasing.
These loadings are leading to more rapid wear of components.
Designers are concerned about these effects on design robustness.
In China and India, harnessing hydro power from silt laden rivers presents yet another set of design challenges.

In Conclusion

Hydropower has much to contribute to our energy situation

Integration with Wind, Solar, and other renewables

Drinking water, irrigation, flood control, navigation, recreation

Significant existing potential remains to be developed

Conventional at existing dams

Wave and Current technologies

Storage

Thank you for your attention.